Air Management

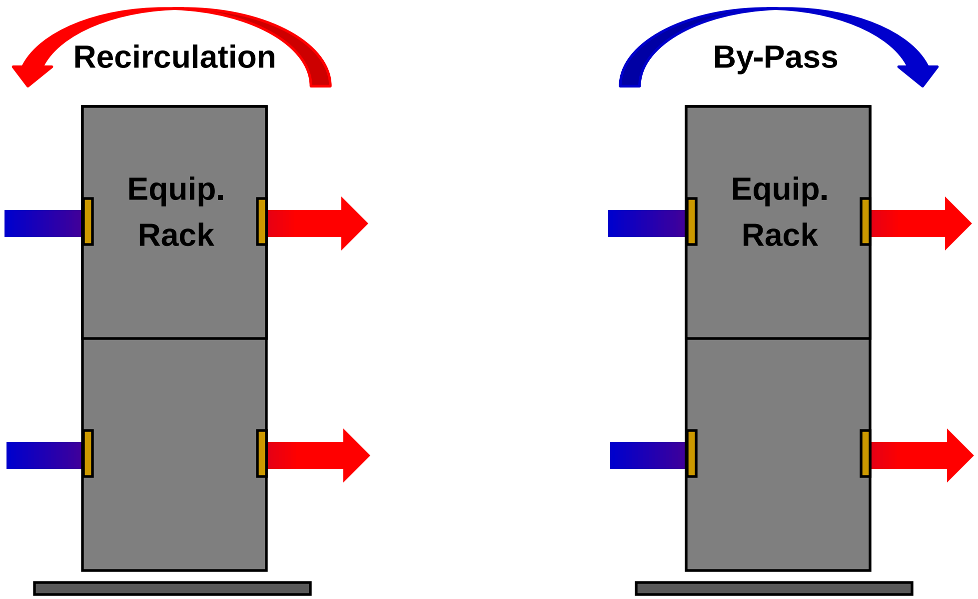
<Presenter>

Review this Presentation to…

- Learn Basic Air Management —Best Practices”
- Detect Common Problems
- Correct Common Problems
- Seek Professional Help.

What is Air Management Anyway?

The goal of Air Management is to minimize *recirculation* of hot air and minimize *by-pass* of cold air in the data center room. Successfully implemented, both measures result in energy savings and better thermal conditions.



Importance of Air Management

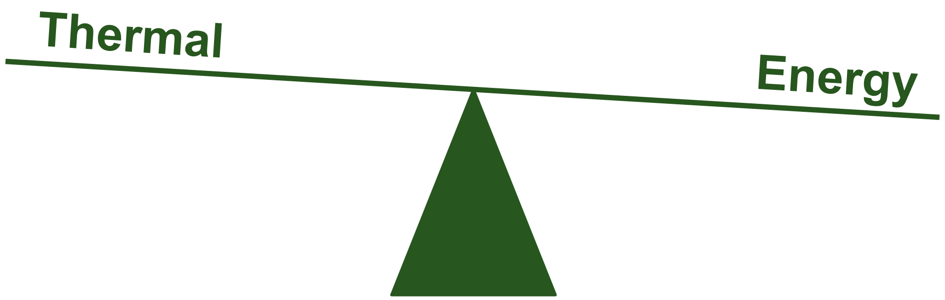
Energy Management. Air Management helps reduce operating costs by enhancing economizer utilization, improving chiller efficiency, and reducing fan energy.

Capital Management. Improved energy efficiency also results in reduced capital investments for cooling equipment, air-moving equipment, and real estate.

Thermal Management. Adequate thermal conditions (intake temperatures) are important for the reliability and longevity of electronic equipment.

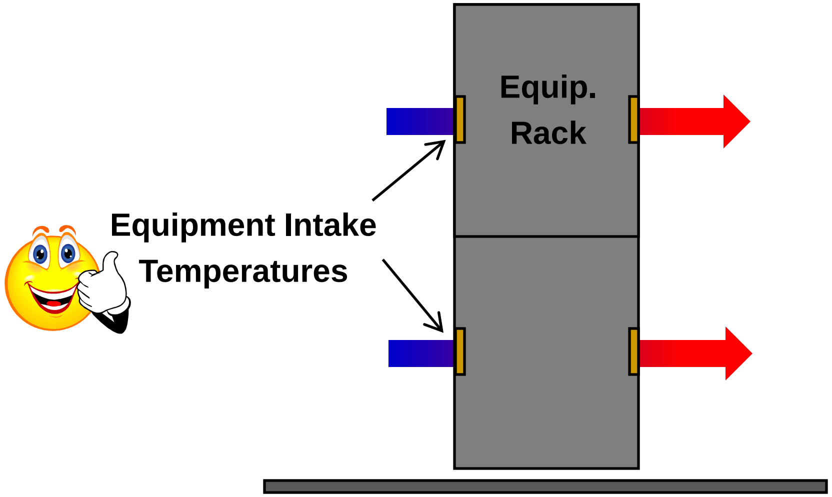
Thermal vs. Energy Performance

One significant difference compared to most other energy-efficiency measures is that Air Management impacts the thermal equipment environment. To avoid sub-optimizations, Air Management must balance the thermal environment and the energy savings.



Equipment Intake Conditions

Air-cooled electronic equipment depends exclusively on the *intake* air temperature for effective cooling. Today, most (but not all) environmental specifications refer to the intake conditions.



Environmental Specifications

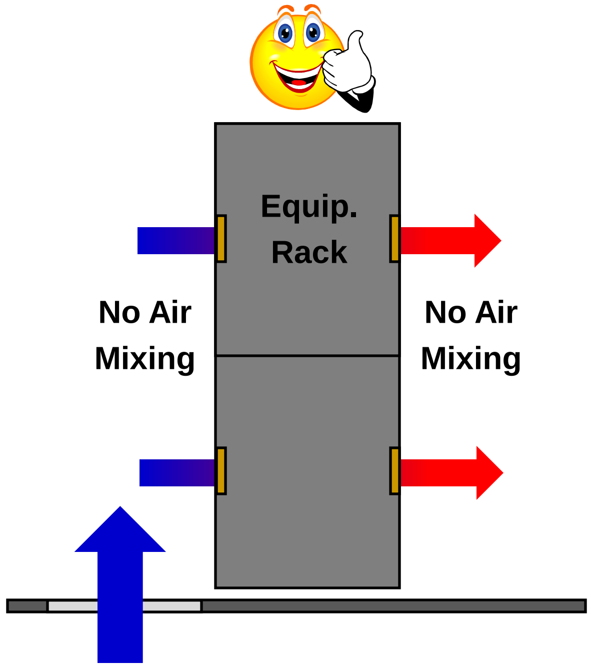
(@ Equipment Intake)	Recommended (Facility)	Allowable (Equipment)
Temperature		
Data Centers ASHRAE	20° – 25°C	15° – 32°C
Telecom NEBS	18° – 27°C	5° – 40°C
Humidity (RH)		
Data Centers ASHRAE	40 – 55%	20 – 80%
Telecom NEBS	≤55%*	5 – 85%

* Assumes Personal Grounding

ASHRAE Reference: ASHRAE (2004); NEBS References: Telcordia (2006 and 2001)

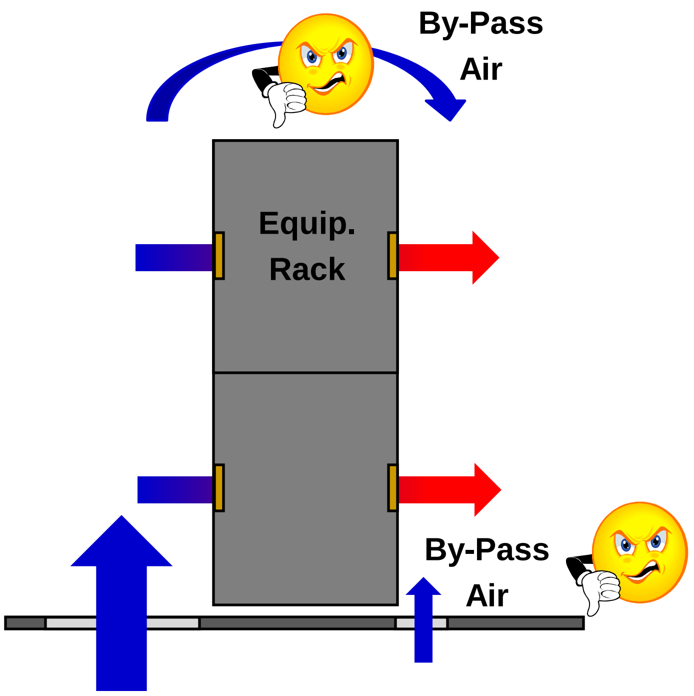
Design for Separation of Cold and Hot Air

The preferred strategy is to supply cold air as close to the equipment intakes as possible without prior mixing with ambient air and return hot exhaust air without prior mixing with ambient air, i.e., *once-through* cooling.



Key Challenge #1: By-Pass Air

By-pass air does not participate in cooling the gear and should be minimized. By-pass air may be caused by an excess of supply air or leakage through cable cutouts.

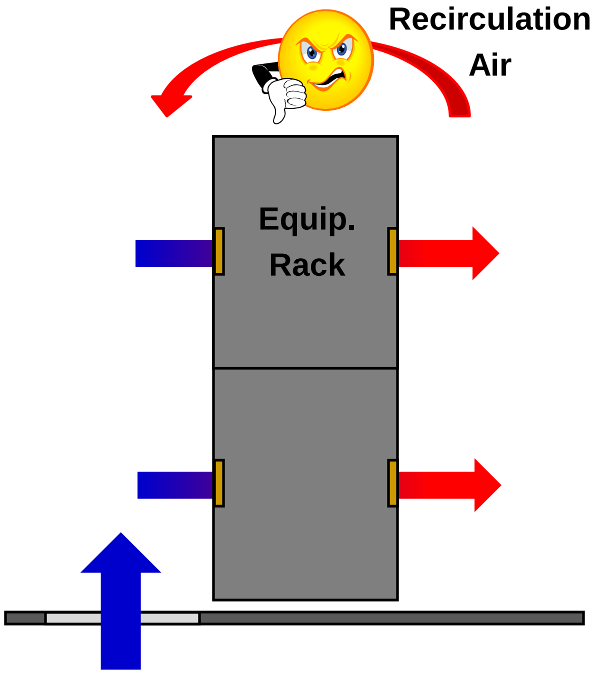


Thermal and Energy Implications

By-pass air increases the operational costs but may be a safeguard against poor thermal conditions. It requires higher system airflow (higher fan energy) and leads to lower return air temperatures (lower chiller efficiency). Reducing the by-pass leads to airflow and cooling capacity regain.

Key Challenge #2: Recirculation Air

Recirculation air participates in cooling the electronic equipment multiple times and should be minimized. Recirculation may be caused by a deficit of supply air.

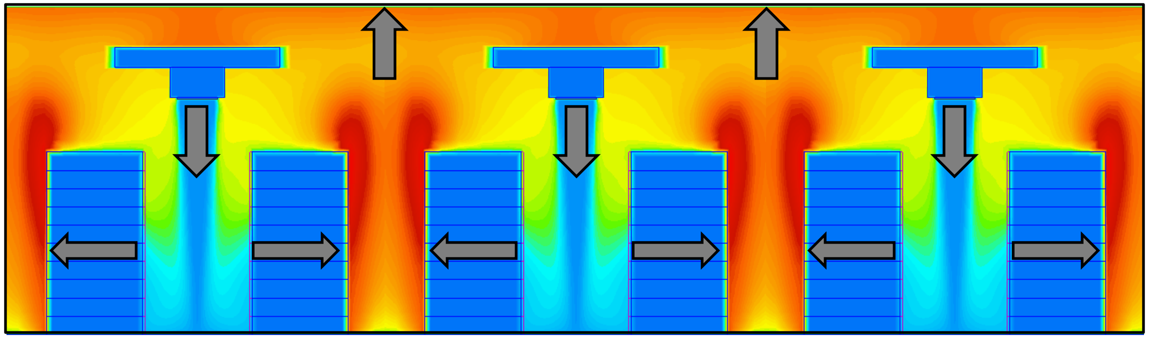


Thermal and Energy Implications

Recirculation air leads to less control of the equipment intake conditions; the implications may be reduced reliability and longevity. Local “hot spots” may lead to a perceived need to increase the overall supply airflow (higher fan energy) or reduce the supply temperature (lower chiller efficiency).

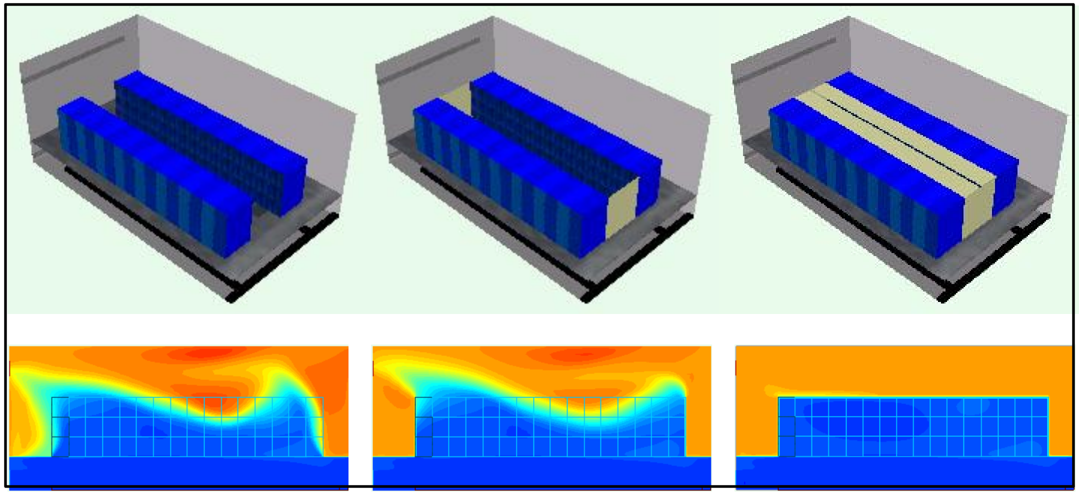
Hot and Cold Aisles

Arranging the space in alternating hot and cold aisles is the first step towards once-through cooling. Cold air is supplied into the cold front aisles, the gear moves the air from the front to the rear, and the hot exhaust air is returned to the air handler from the hot rear aisles.



Room Architectures

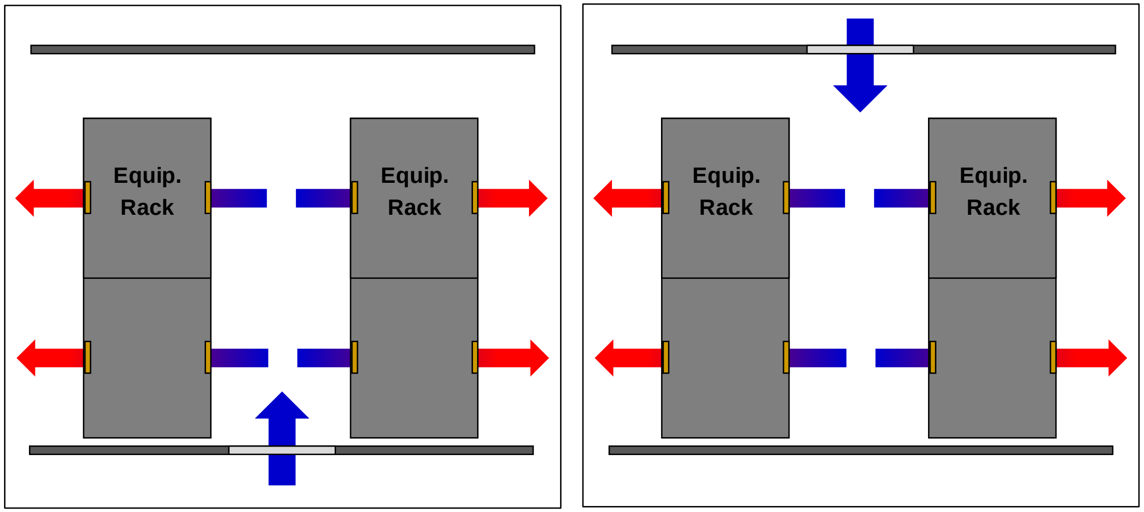
Physical barriers can successfully be used to enhance the separation of hot and cold air. Enclosed aisles permit high supply and—in turn—return temperatures.



Open **Semi-enclosed** **Enclosed**

Under-Floor vs. Over-Head Cooling

Correctly designed, both cooling methods work well; each has its own benefits and drawbacks. Changing from one to the other is generally not an option.



Tall Ceilings vs. Return Plenum

Tall open ceilings promote thermal stratification and the placement of the return grilles is not critical. A return plenum often means a lower clear ceiling but allows placing the return grilles above the hot aisles. Open tall ceilings have an unmatched simplicity compared to return plenums.

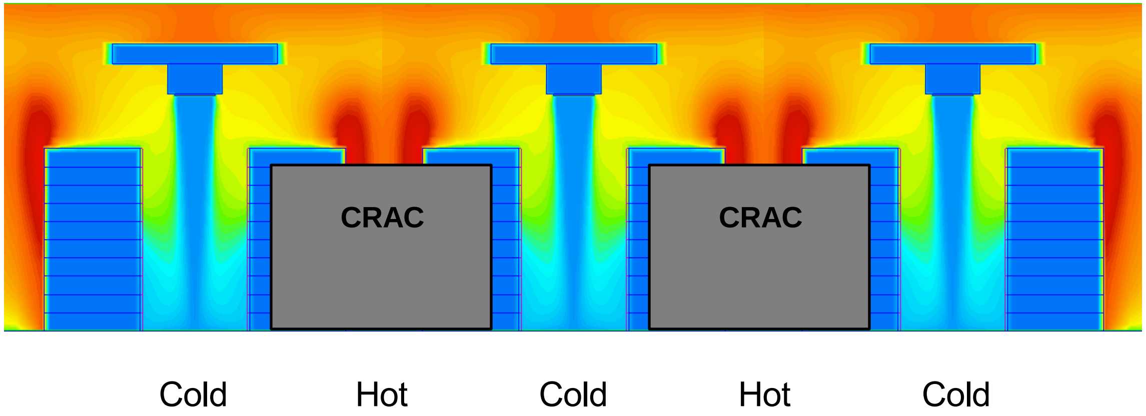
Raised-Floor Height

The cooling capacity of a raised floor depends on its *effective* height, which can be increased by removing cables and other obstructions that are not in use.

The cooling capacity is generally limited by pressure variations in the plenum, which lead to erratic cooling airflow rates. Equipment aisle enclosures can increase the capacity since variations in the airflows cancel out inside the enclosure.

Location of CRAC Units

CRAC units should be placed to promote an even pressure distribution in the floor plenum. Although it may seem counter-intuitive, center them on the hot aisles rather than on the cold aisles results in better cooling performance.



Pressure Drop vs. Airflow Stability

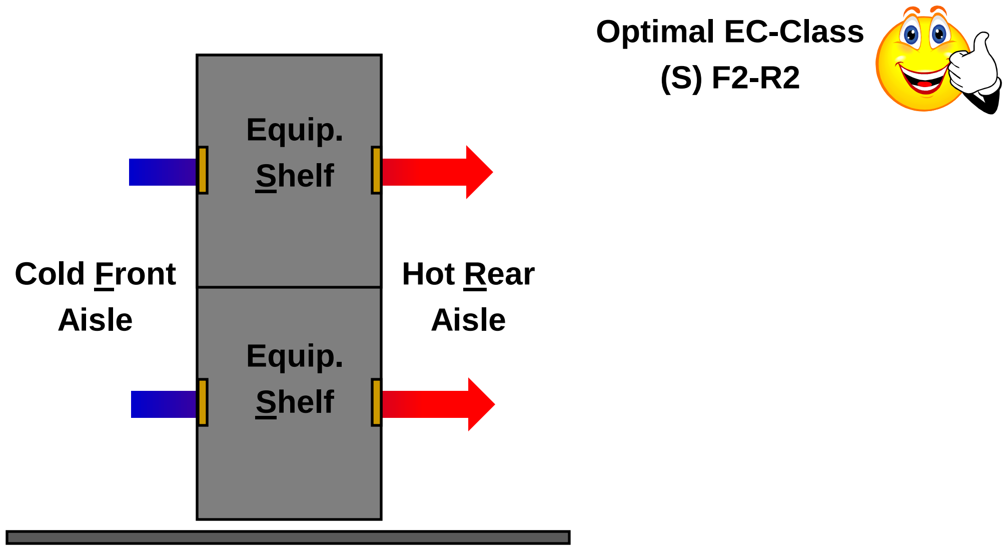
Low pressure drops result in low energy costs. Or so is the thinking. But low pressure drops at the *diffuser level* affect airflow stability. For example, over-head ducted systems generally have better stability than raised-floor systems. Higher pressure losses buy higher stability, which may result in lower energy usage over time.

Vary Supply Airflow—Not Supply Temperature

Traditionally, few CRAC units had the capability to vary the airflow in real time, and adjusting the temperature was the only option. With variable speed drives, the capacity control should be modified to improve the cooling effectiveness of the electronic equipment as well as save fan and cooling energy. The supply airflow should closely match the equipment airflow; too little or too much supply air degrades the performance.

Equipment-Cooling (EC) Classes

The EC-Class describes where the entry and exit points for the cooling air are located on the equipment envelope. An *optimal* Class moves air from the cold front aisle to the rear hot aisle, conserving the hot and cold aisles.



Air Balancing

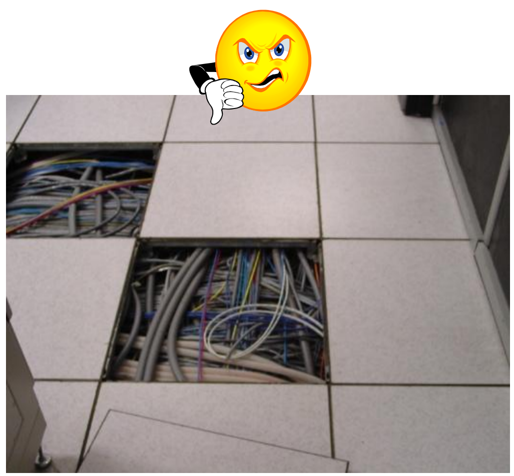
When changes are made to the electronic equipment inventory, the air-distribution system needs eventually to be rebalanced. A system out of balance results in a degraded thermal equipment environment and often higher airflow rates and energy costs to combat hot spots. Relatively high pressure drops at the *diffuser level* improve the chances for a successful balancing.

Perforated Floor Tiles

Perforated floor tiles (or over-head diffusers) should only be placed in the cold aisles to match the “consumption” of air by the electronic equipment. Too little or too much supply air results in poor overall conditions. The hot aisles are supposed to be hot and perforated tiles should not be placed in those areas. A rigorous program should be in place to maintain the hot and cold aisle configuration of perforated floor tiles.

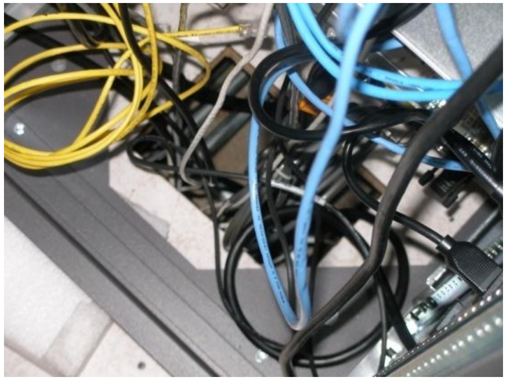
Cable Congestion

Cable congestion in raised-floor plenums can sharply reduce the total airflow as well as degrade the airflow distribution through the perforated floor tiles. Often, it is quite obvious when there is too much —stuff.”



Maintain Tight Raised Floors

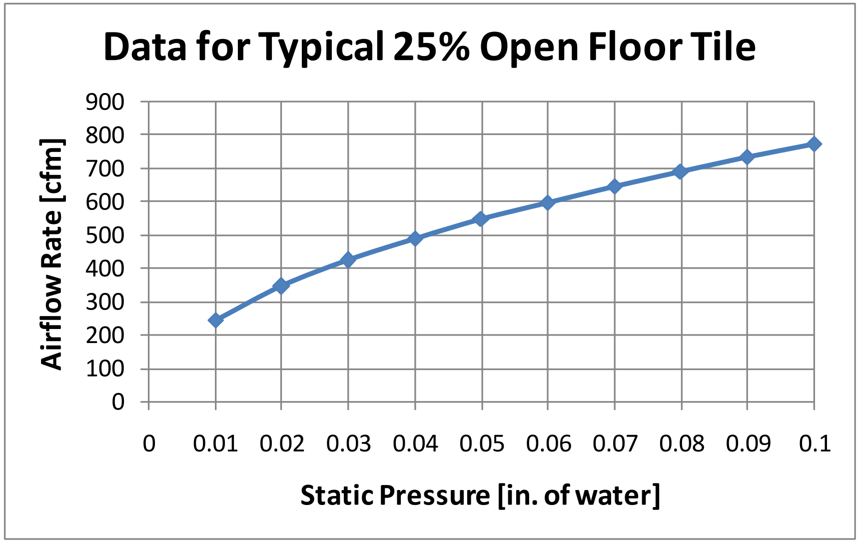
A large fraction of the air from the air-handler(s) is often lost through leaks in the raised floor. Such leakage causes by-pass air that does not contribute to cooling the electronic equipment. A rigorous program should be in place to maintain the raised floor and the plenum.



Unsealed cable penetration

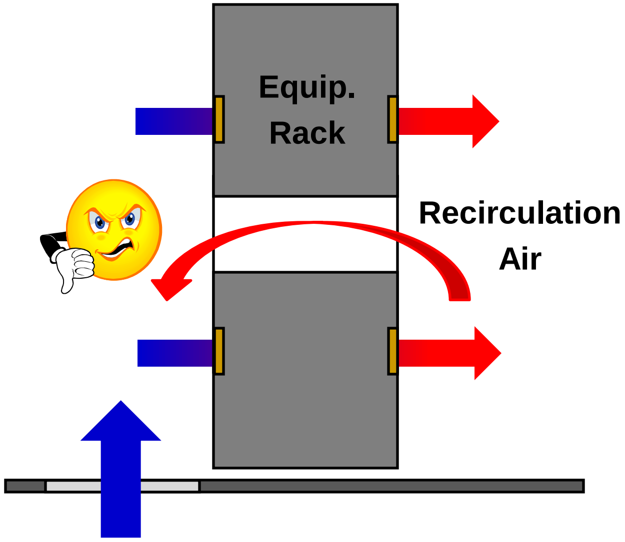
Raised-Floor Plenum Pressure

A high raised-floor plenum static pressure means high floor leakage and by-pass air. A mid-range static pressure may be considered since it allows relatively high tile airflow rates but caps the floor leakage.



Managing Blanking Panels

Managing blanking panels and unbroken equipment lineups is especially important in hot and cold aisle environments. *Any* opening between the aisles will degrade the separation of hot and cold air. A rigorous program should be in place to maintain the panels.



Performance Metrics

Metrics play an important role in providing a measure of the performance of Air-Management systems. They condense unwieldy information to understandable, objective, and standardized numbers. Air-Management metrics include the Rack Cooling Index (RCI) and the Return Temperature Index (RTI).

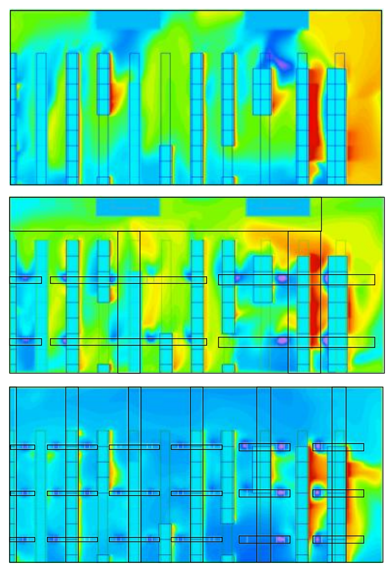
Computational Fluid Dynamics (CFD) Modeling

CFD modeling estimates temperature, airflow, and pressure fields in the data center. Although modeling provides a wealth of information, sorting things out in terms of equipment cooling is often a great challenge.

Good?

Better?

Best?



Plan views of three equipment rooms with temperature maps

Air-Management Metrics: Overview

Rack Cooling Index (RCI).

The RCI is a measure of how *effectively the equipment is cooled* and maintained within an intake temperature specification. The index helps evaluate the equipment cooling —effectiveness.”

Interpretation: 100% is ideal; <90% is often considered poor.

Return Temperature Index (RTI).

The RTI is a measure of the *level of by-pass air or recirculation air* in data centers. Both phenomena are detrimental to the thermal and energy performance of the facility.

Interpretation: 100% is the target; >100% $\rightarrow$ recirculation air; <100% $\rightarrow$ by-pass air.

Air-Management Metrics: Overview

Supply Heat Index (SHI).

The SHI is a dimensionless measure of *recirculation of hot air into the cold aisles*. SHI not only provide a tool to understand convective heat transfer in the equipment room but also suggest means to improve the energy efficiency.

Interpretation: SHI is a number between 0 and 1, the lower the better. SHI is typically < 0.40.

Air-Management Metrics: The Details

$$RCI_{HI} = \left[1 - \frac{\sum_{x=1}^{n} (T_x - T_{max-rec})}{(T_{max-all} - T_{max-rec})n} \right] 100[\%] \ (for\ T_x > T_{max-rec})$$

T_x	Temperature at equipment intake x
n	Total number of intakes
$T_{max-rec}$	Max recommended intake temperature
$T_{max-all}$	Max allowable intake temperature

$$RCI_{LO} = \left[1 - \frac{\sum_{x=1}^{n} (T_{min-rec} - T_x)}{(T_{min-rec} - T_{min-all})n} \right] 100[\%] \ (for\ T_x < T_{min-rec})$$

T_x	Temperature at equipment intake x
n	Total number of intakes
$T_{min-rec}$	Min recommended intake temperature
$T_{min-all}$	Min allowable intake temperature

$$RTI = \left[\frac{T_R - T_S}{\Delta T_{Equip}} \right] 100[\%]$$

T_R	Return temperature (airflow weighted)
T_S	Supply temperature (airflow weighted)
ΔT_{Equip}	Average temperature rise across equipment (airflow weighted)

RCI Reference: Herrlin (2005); RTI Reference: Herrlin (2008)

Air-Management Metrics: The Details

$$SHI = \left(\frac{\sum_j \sum_i \left((T_{in}^{r})_{i,j} - T_{ref} \right)}{\sum_j \sum_i \left((T_{out}^{r})_{i,j} - T_{ref} \right)} \right)$$

Where:

Where:	i and j	Specific racks and rows, respectively (e.g., i,j = 1,2 means rack 1 in row 2)
	T_{in}^{r}	Rack air inlet temperature (assuming one air inlet)
	T_{out}^{r}	Rack air outlet temperature (assuming one air outlet)
	T_{ref}	Reference (supply air into space) temperature

SHI Reference: Sharma et al (2002)

Application Example

An analysis of an LBNL data center resulted in the following key metric values. Without these metrics, it would have been difficult to communicate the overall Air-Management status in a concise fashion.

Metric	Value	Air-Management Interpretation
RCI_{HI}	100%	No intake temperature above the recommended range (ideal)
RCI_{LO}	47%*	Severely over-cooled space (<90% means “poor”)
RTI	53%	Severely over-ventilated space; by-pass air of 89% (1/0.53)
HD	58 W/ft^2	Moderate heat density.

Detecting Common Air-Management Problems

This curriculum is intended to be the first step in the development of resident expertise. Although it provides only an overview of Air Management, knowing the basics allows detecting many common problems.

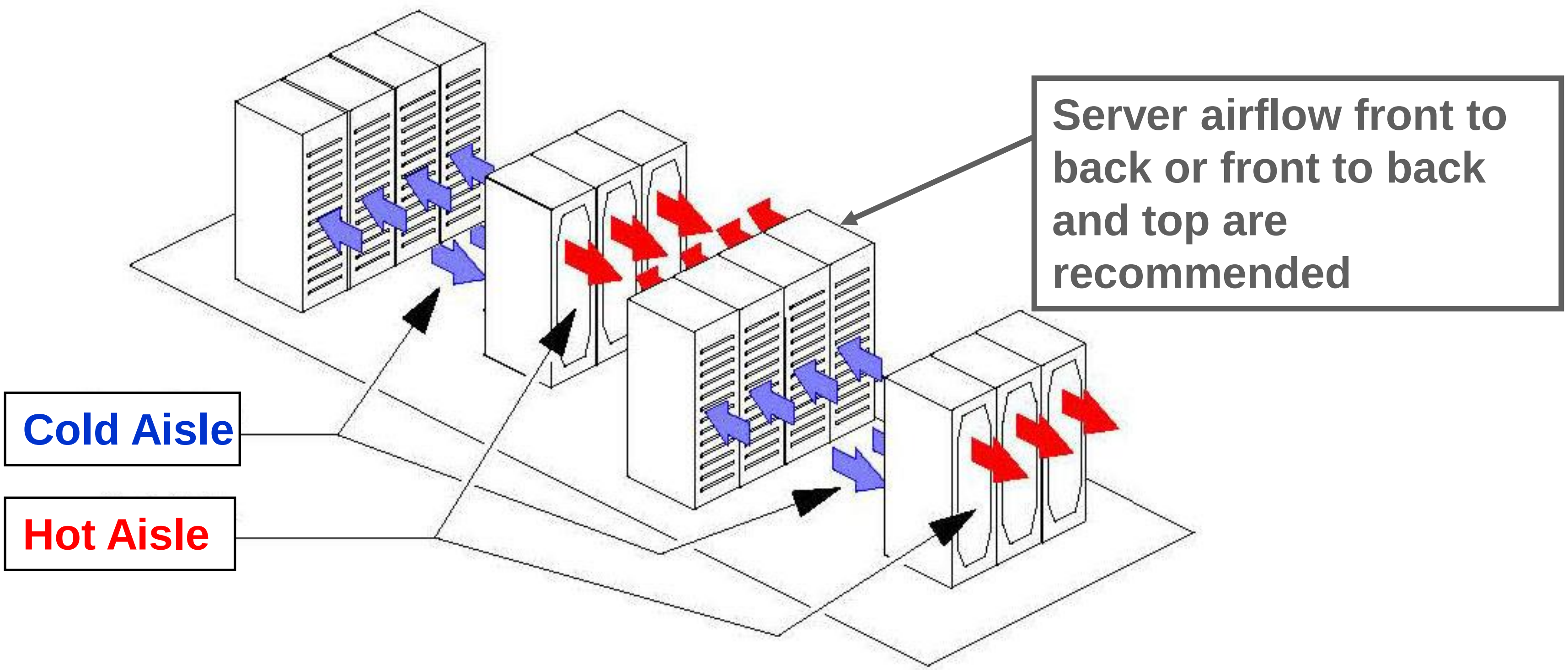
Correcting Common Air-Management Problems

The ability to detect common problems is the initial step towards correcting them. This curriculum encourages replication of concepts and provides pointers to correct common Air-Management problems.

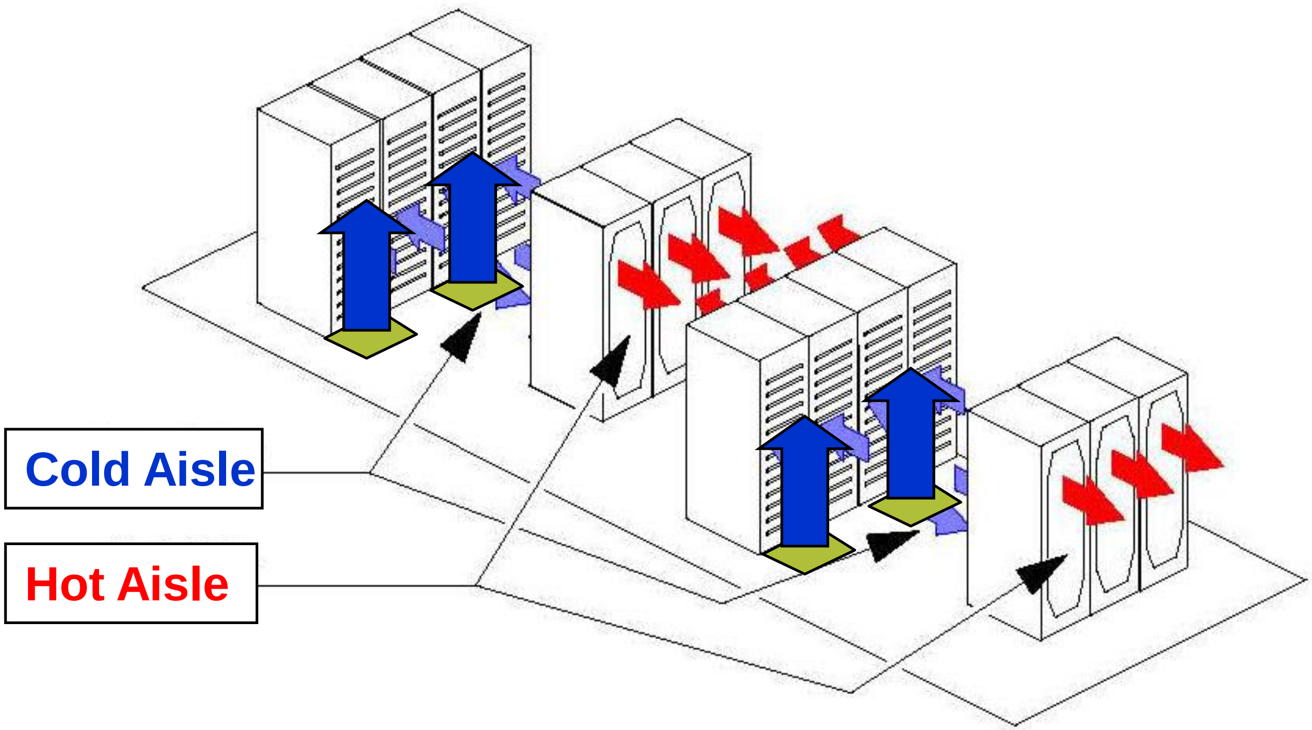
Professional Help

Knowing when to seek help is key to successful Air Management. This curriculum is not intended to provide answers to all related questions. Professionals specialized in Air Management should be able to assist when your expertise has been exhausted. Addressed correctly, Air Management has the unique potential to improve equipment cooling *and* lower the energy bills.

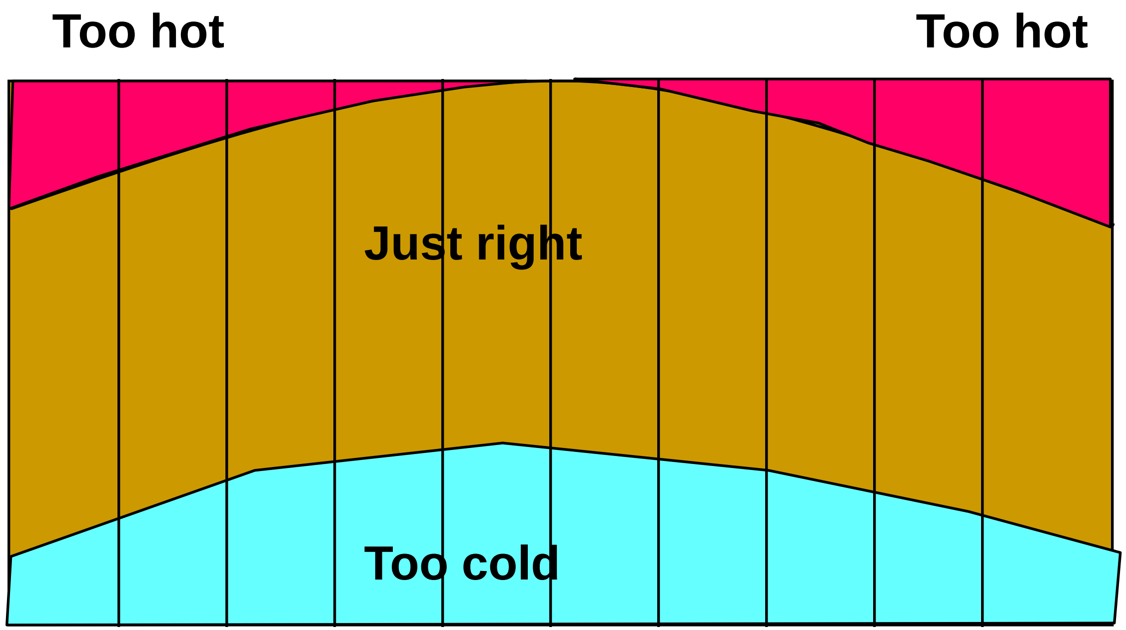
Data center layout



Underfloor supply



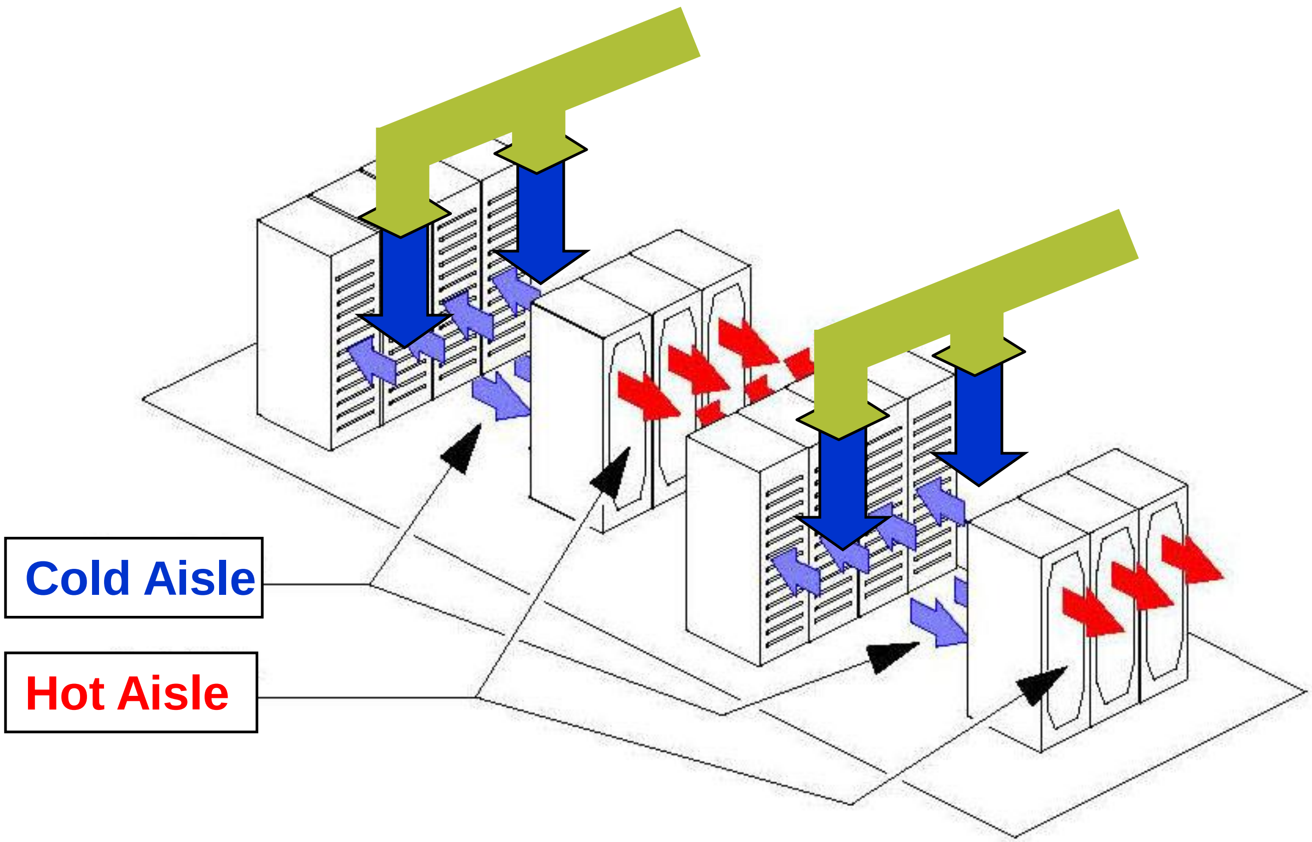
Typical temperature profile with underfloor supply



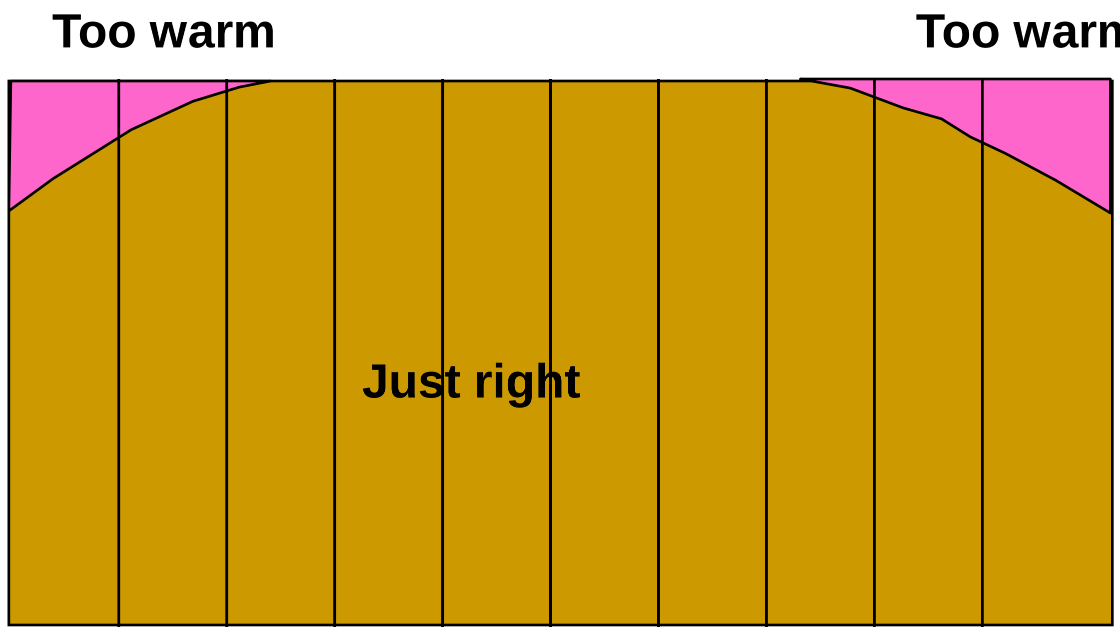
Elevation at a cold aisle looking at racks

There are numerous references in ASHRAE. See for example V. Sorell et al; "Comparison of Overhead and Underfloor Air Delivery Systems in a Data Center Environment Using CFD Modeling"; ASHRAE Symposium Paper DE-05-11-5; 2005

Overhead supply



Typical temperature profile with overhead supply



Elevation at a cold aisle looking at racks

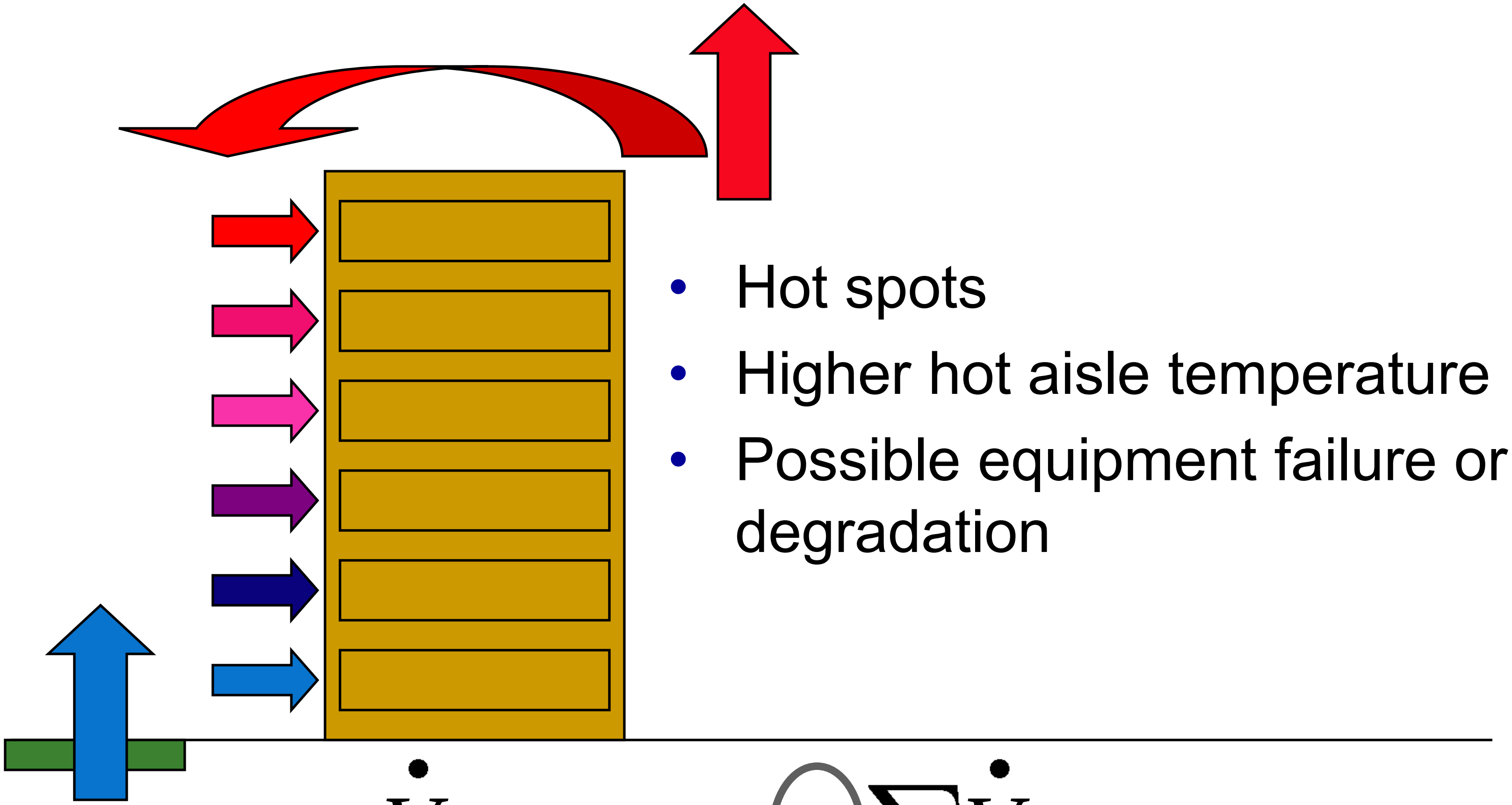
Overhead (OH) vs. underfloor (UF)

Issue	Overhead (OH) Supply	Underfloor (UF) Supply
Capacity	Limited by space and aisle velocity.	Limited by free area of floor tiles.
Balancing	Continuous on both outlet and branch.	Usually limited to incremental changes by diffuser type. Some tiles have balancing dampers. Also underfloor velocities can starve floor grilles!
Control	Up to one pressure zone by branch.	Only one pressure zone per floor, can provide multiple temperature zones.
Temperature Control	Most uniform.	Commonly cold at bottom and hot at top.
First Cost	Best (if you eliminate the floor).	Generally worse.
Energy Cost	Best.	Worst.
Aisle Capping	Hot or cold aisle possible.	Hot or cold aisle possible.

Airflow design disjoint

- IT departments select servers and racks – each having airflow requirements
- Engineers size the facility fans and cooling capacity
- What's missing
  in this picture?

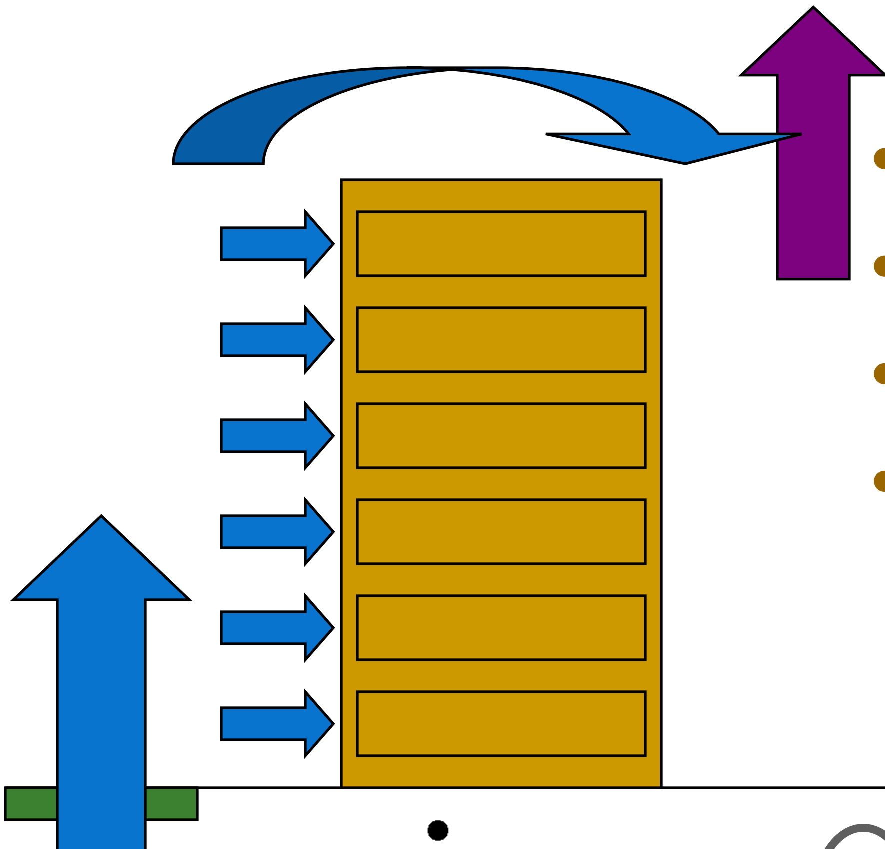
What happens when the HVAC systems have less airflow than the servers?



- Hot spots
- Higher hot aisle temperature
- Possible equipment failure or degradation

$$\dot{V}_{HVAC\_Supply} < \sum \dot{V}_{Servers}$$

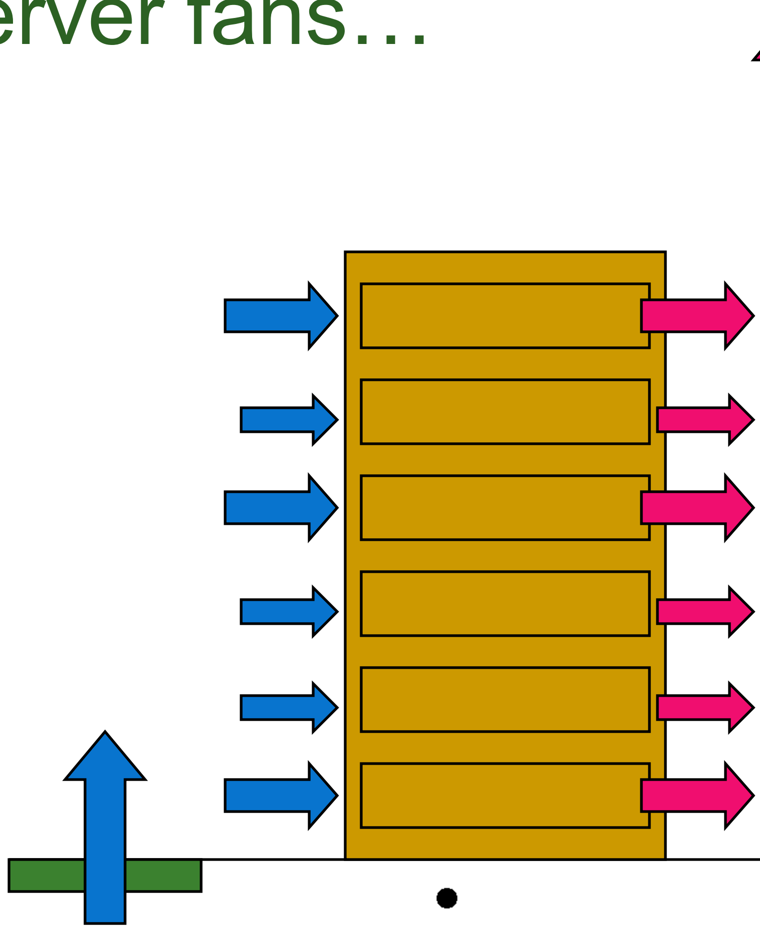
What happens when the HVAC systems have more airflow than the servers?



- Least hot spots
- Higher air velocities
- Higher fan energy
- Reduced economizer effectiveness (due to lower return temperatures)

$$\dot{V}_{HVAC\_Supply} > \sum \dot{V}_{Servers}$$

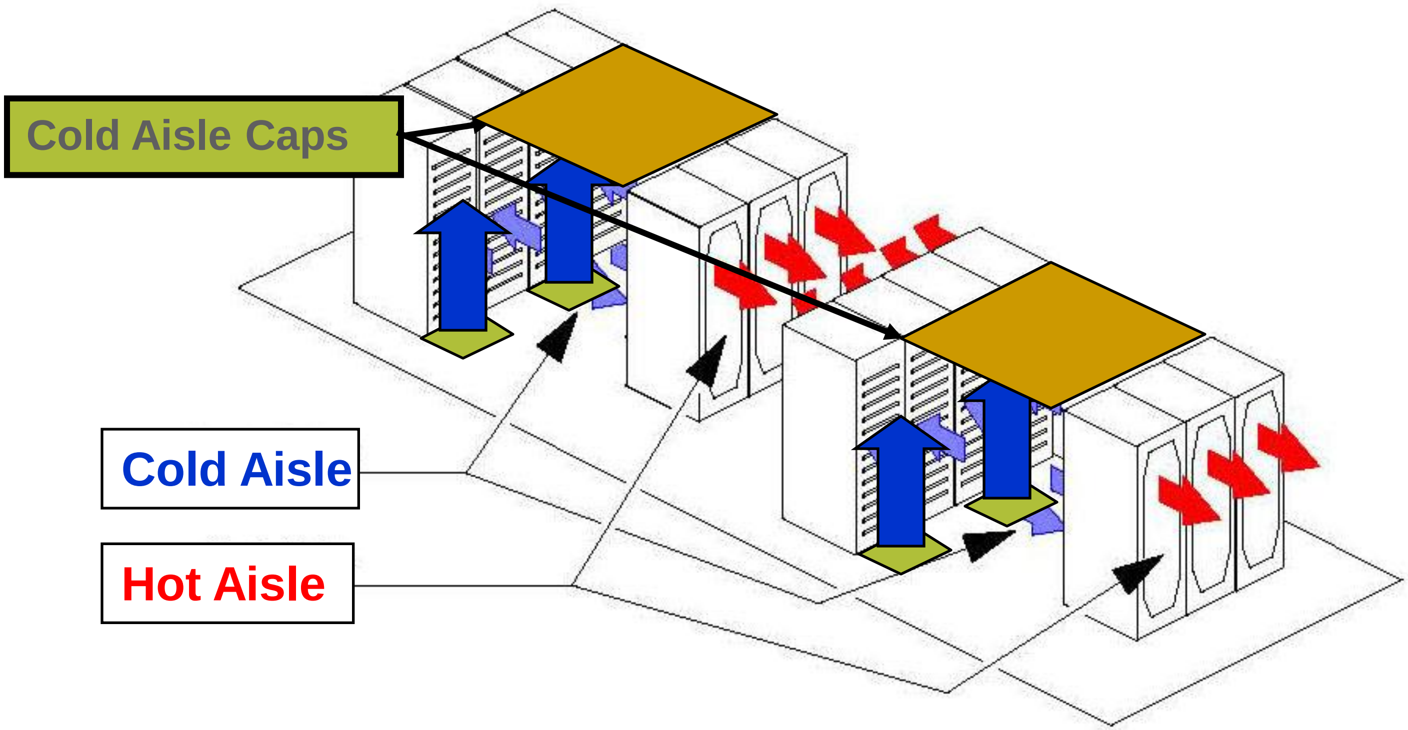
In a perfect world, variable flow supply and server fans…



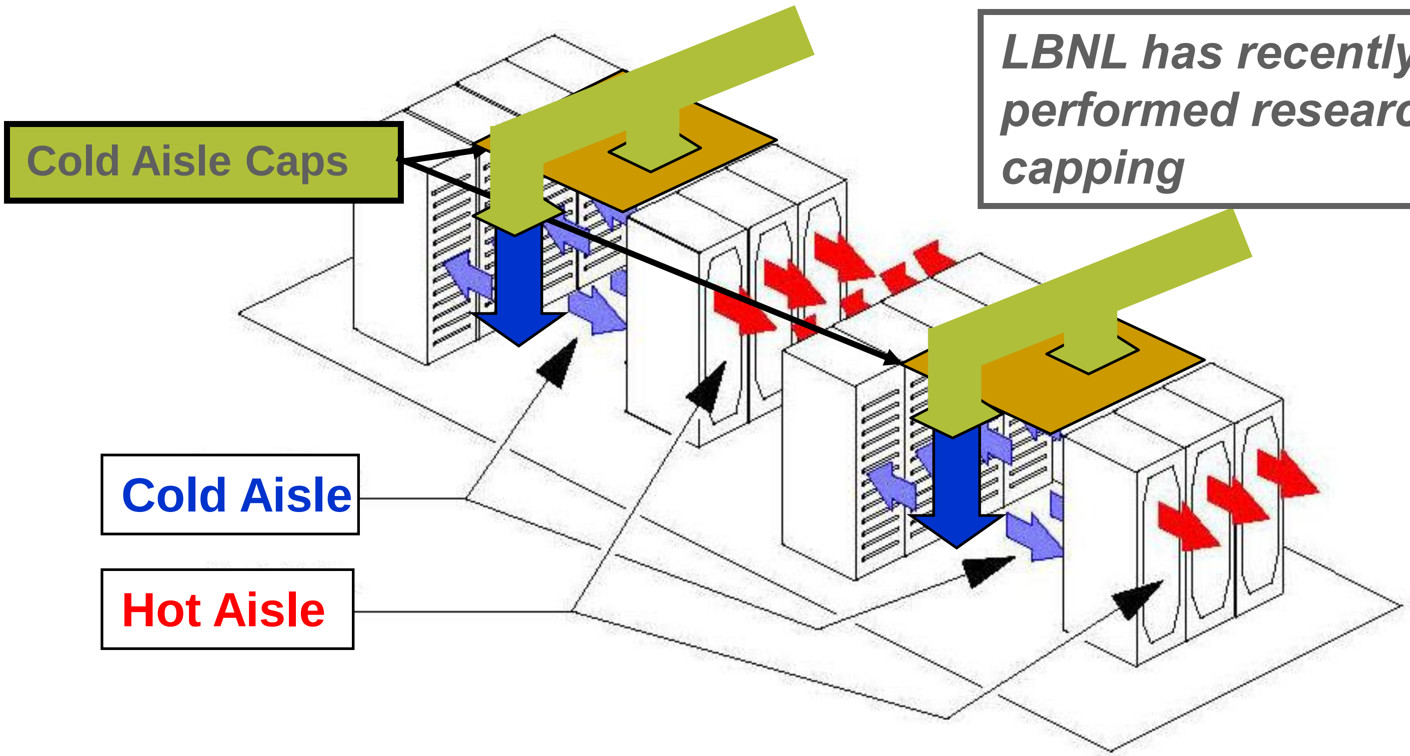
- Partial flow condition
- Best energy performance but tricky to control
- Works best with aisle containment

$$\dot{V}_{HVAC\_Supply} > \sum \dot{V}_{Servers}$$

Aisle capping



Aisle capping

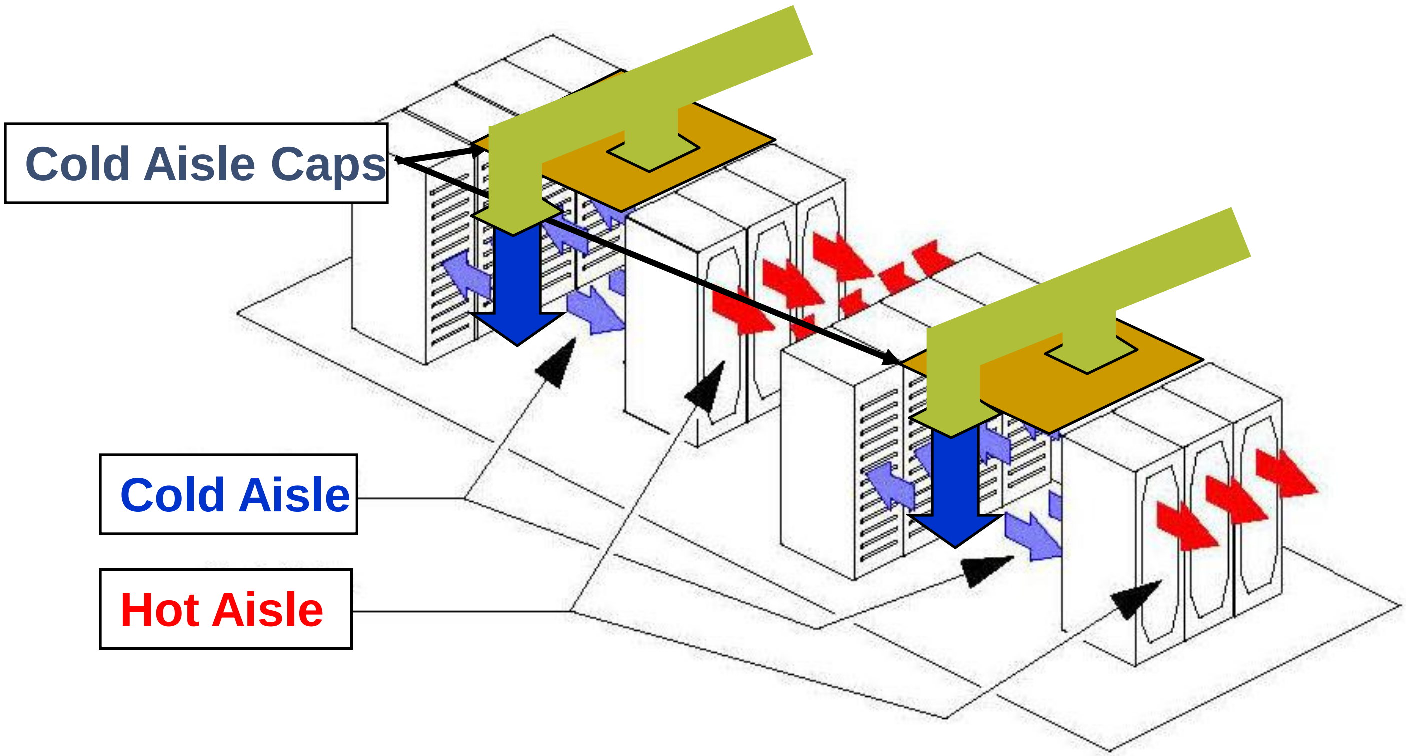


LBNL has recently performed research on aisle capping

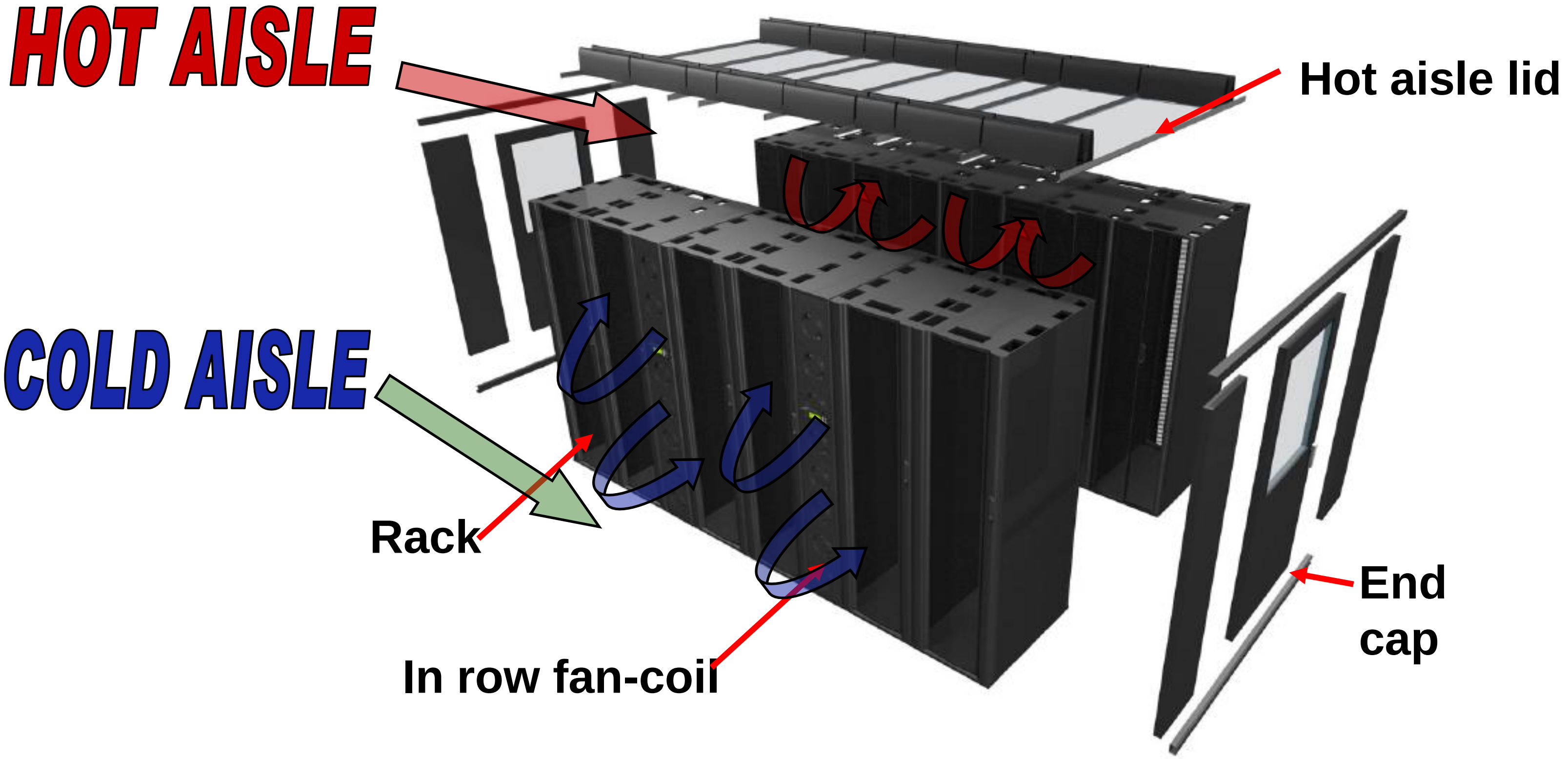
Isolating hot or cold aisles

- Energy intensive IT equipment needs good isolation of “cold” inlet and “hot” discharge
- Computer room air conditioner airflow can be reduced if no mixing occurs
- Overall temperature can be raised in the data center if air is delivered to equipment without mixing
- Coils and chillers are more efficient with higher temperature differences

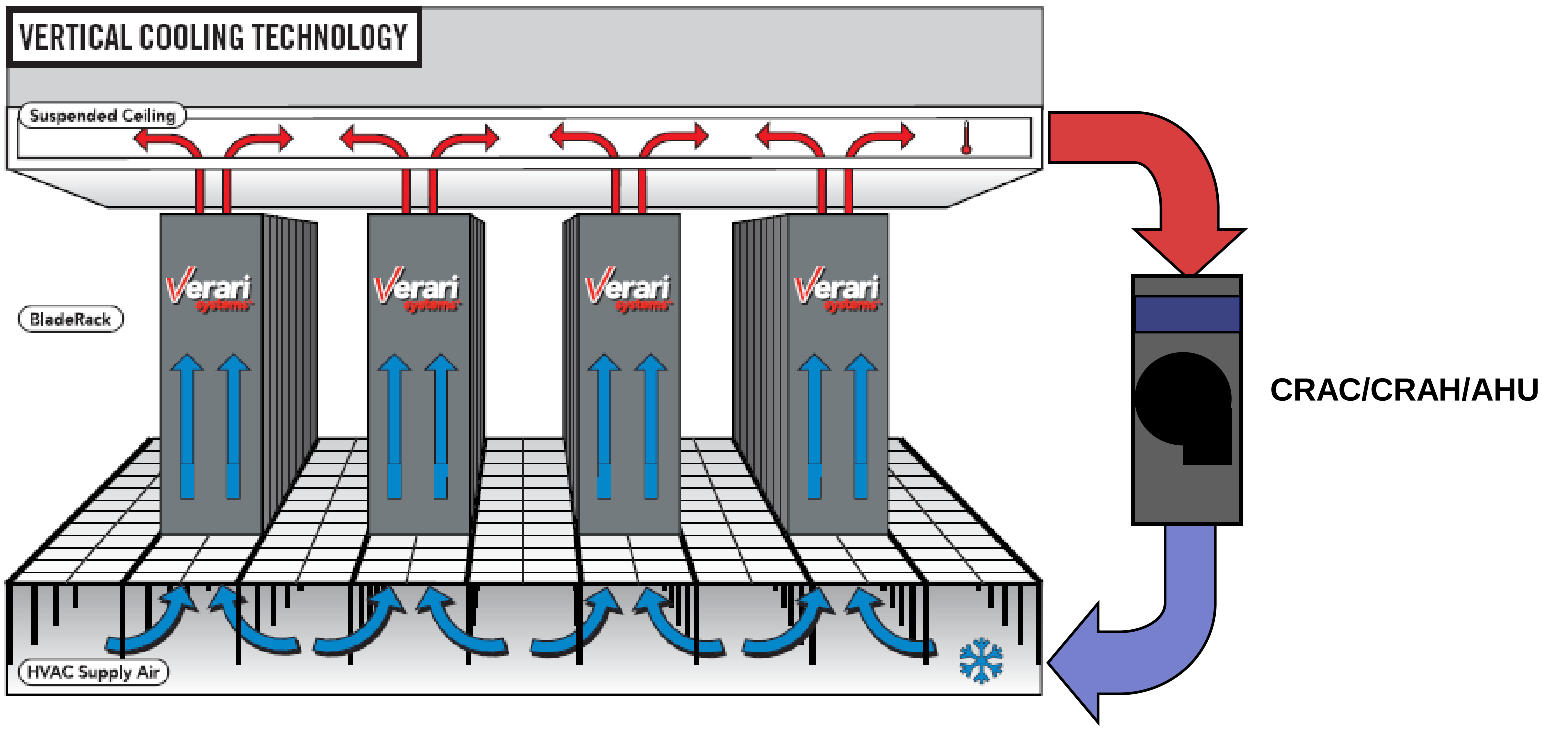
Cold-aisle containment, overhead supply



Hot-aisle containment with in row cooling



Hot- and cold-aisle containment



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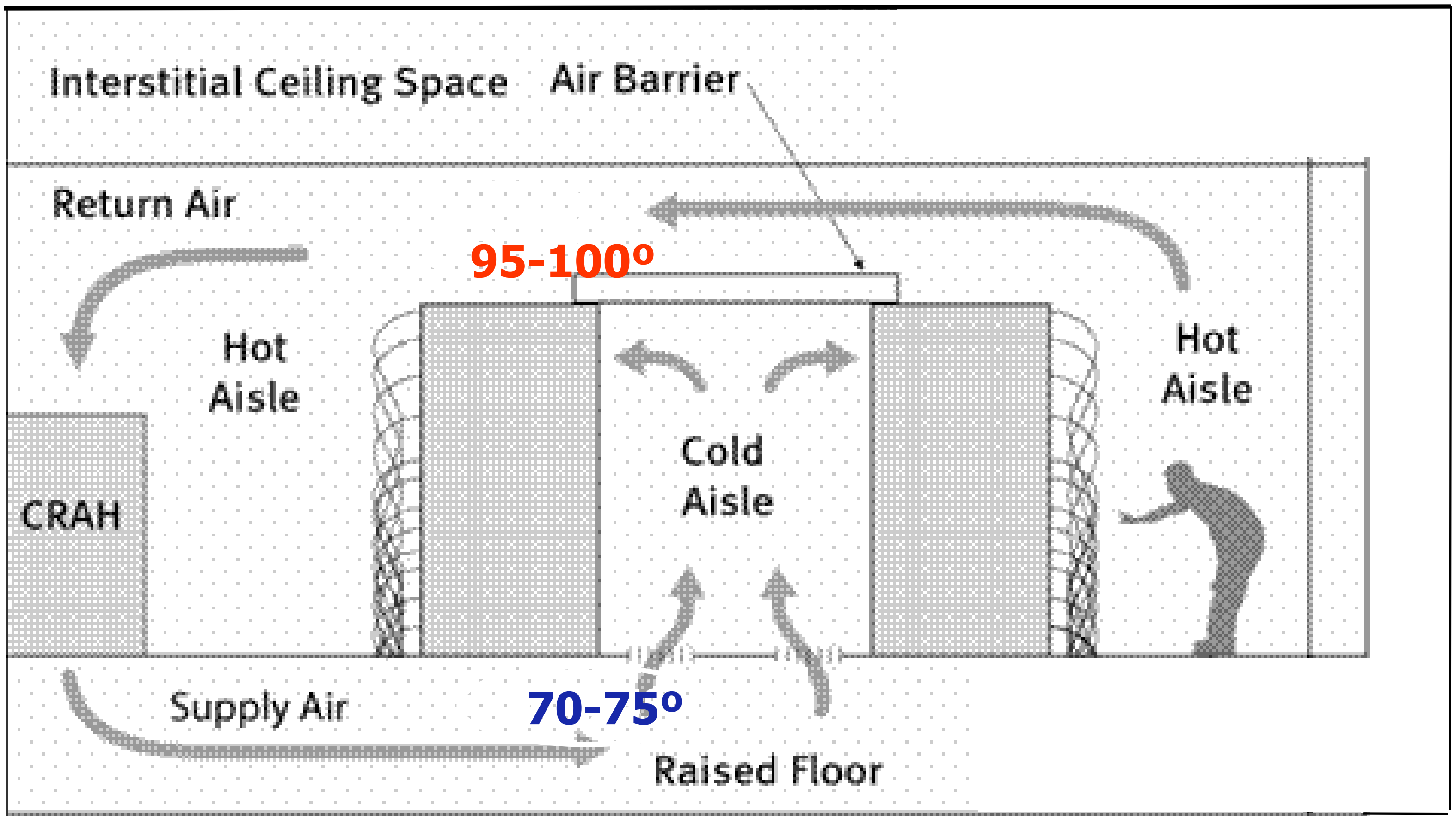
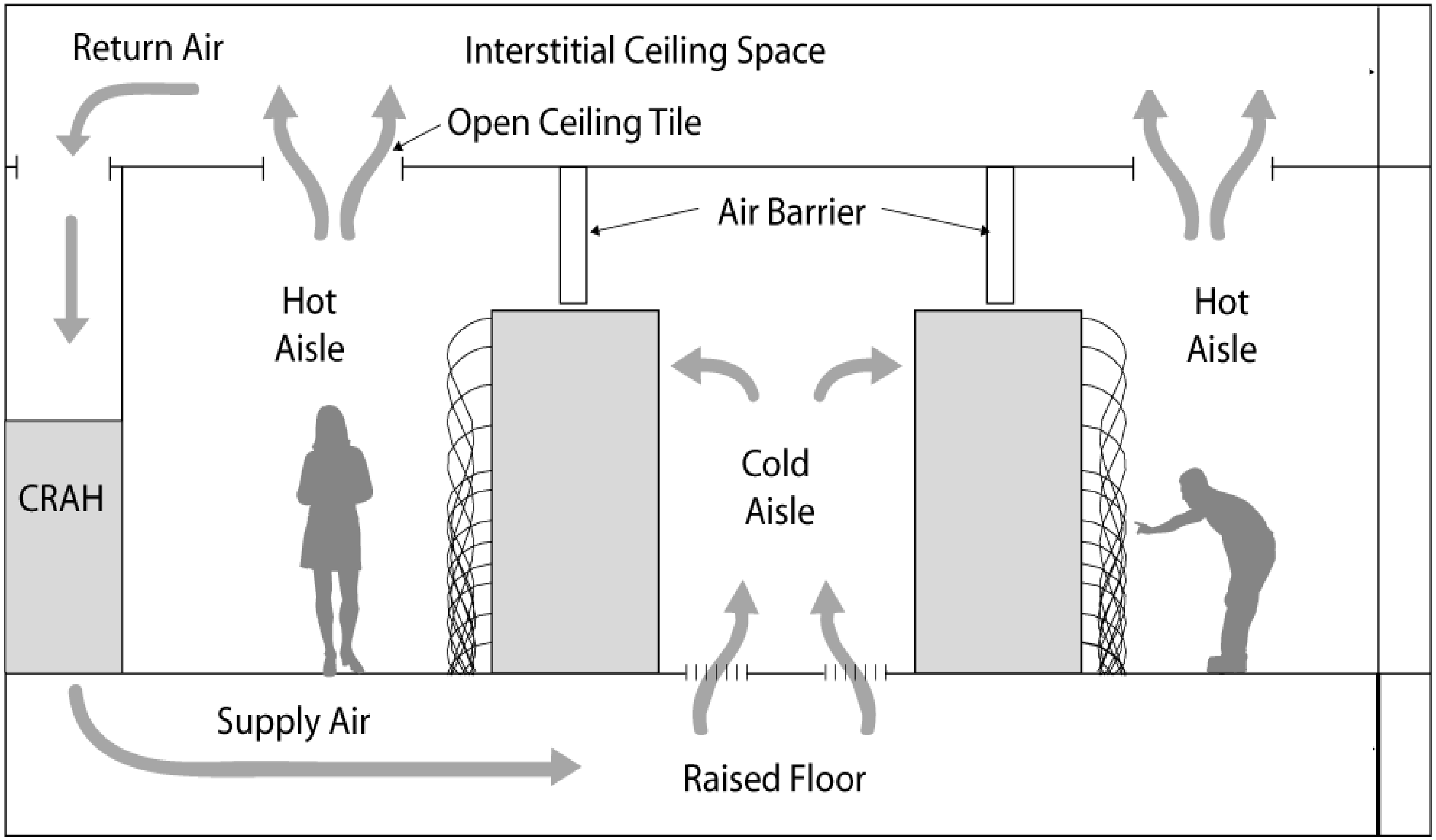
LBNL Air Management Demonstration

- Two configurations
  - Isolate —cold aisle”
  - Contain —hot aisle”, use ceiling plenum, and extend CRAC inlet to ceiling
- Lower airflow using existing VFD’s
- Raise under floor temperature
- Increase ΔT – more efficient cooling

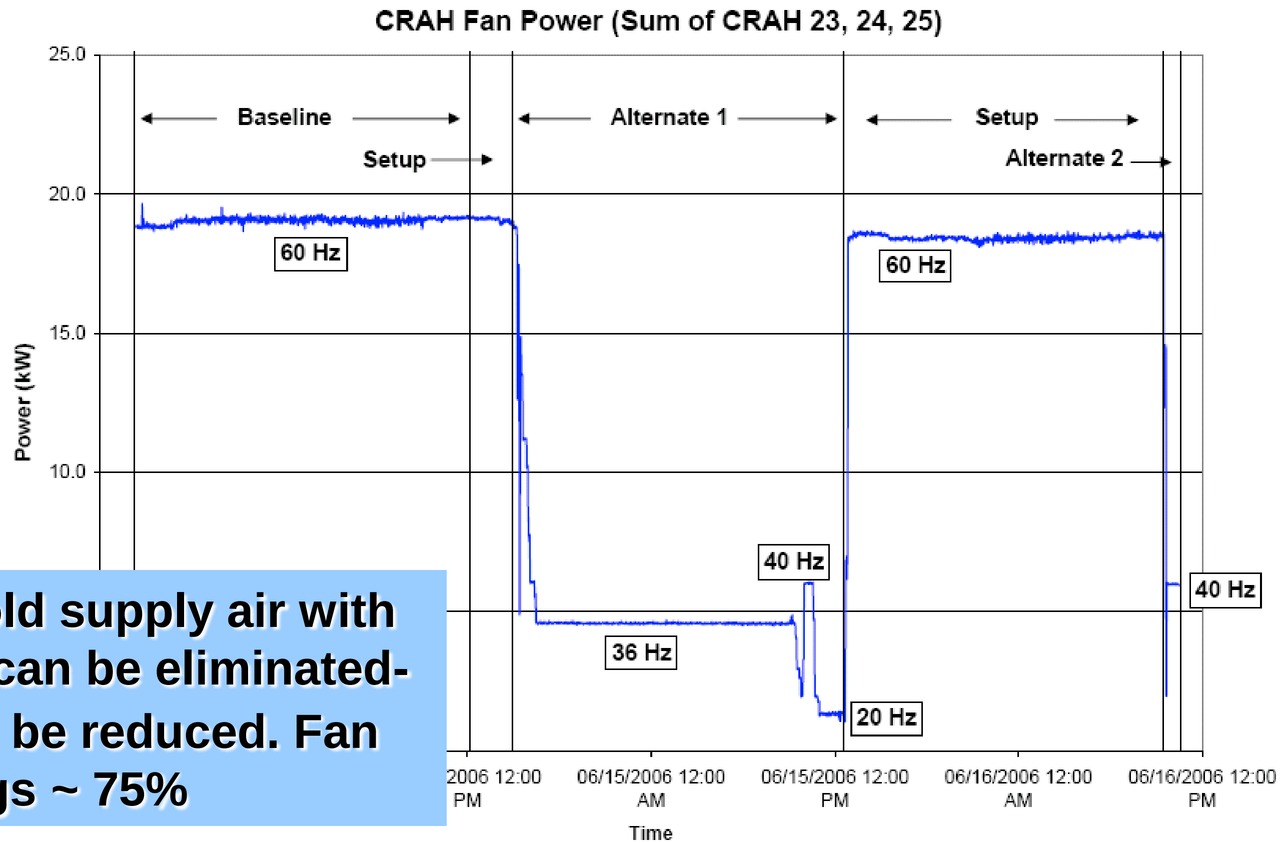
Cold-aisle containment, under-floor supply



Another isolation scheme



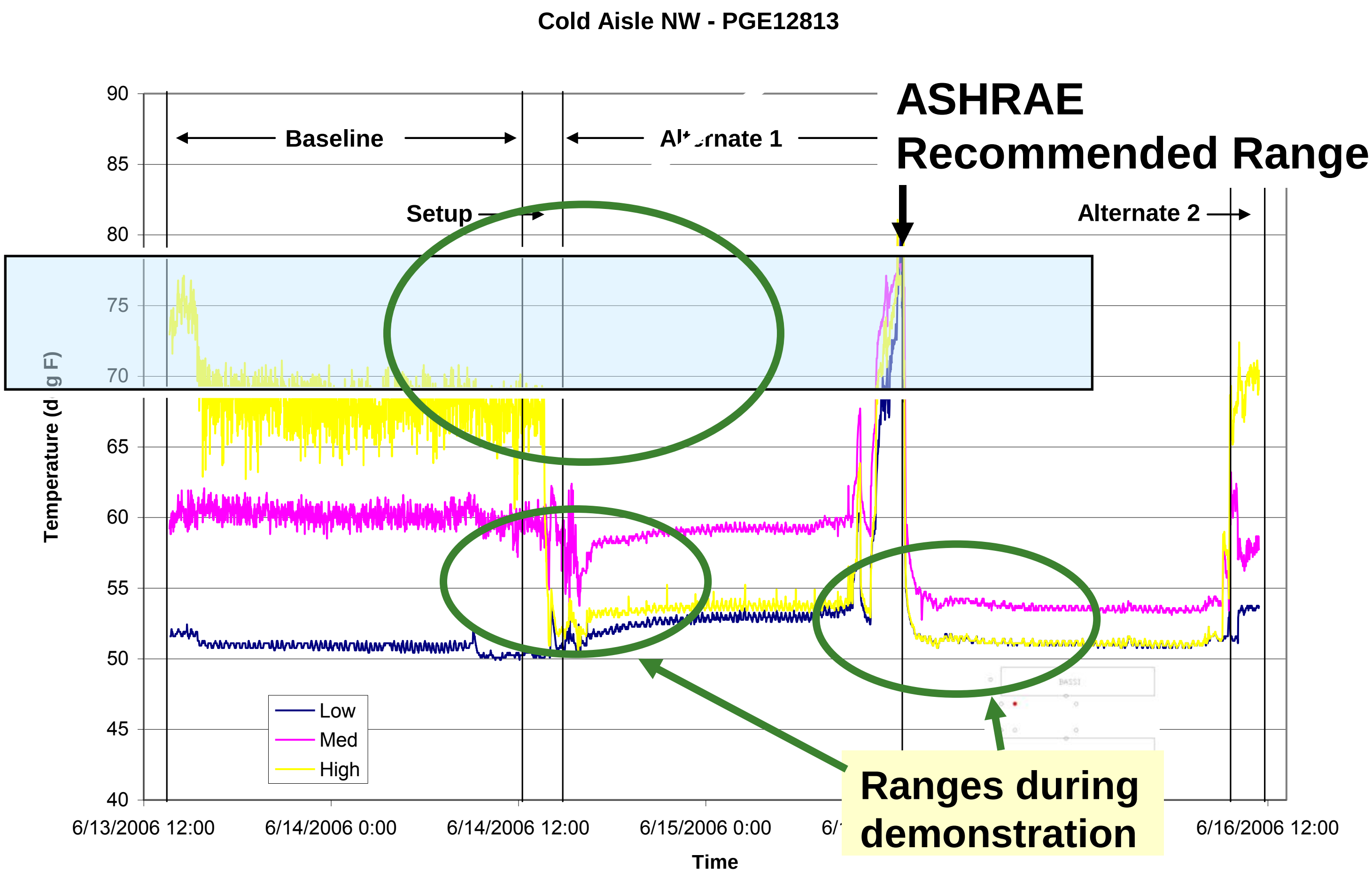
Fan Energy Savings – 75%



If mixing of cold supply air with hot return air can be eliminated- fan speed can be reduced. Fan Energy Savings ~ 75%

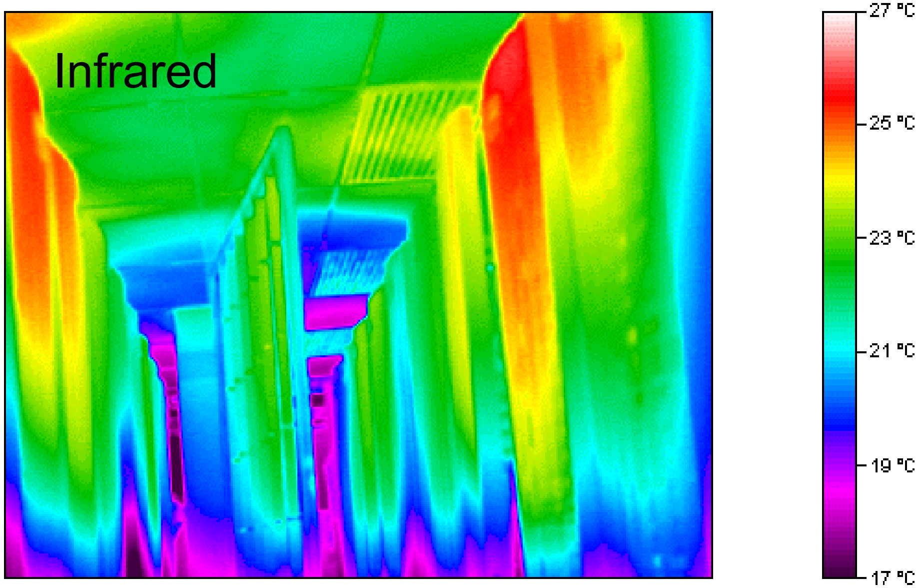
LBNL cold-aisle containment demo

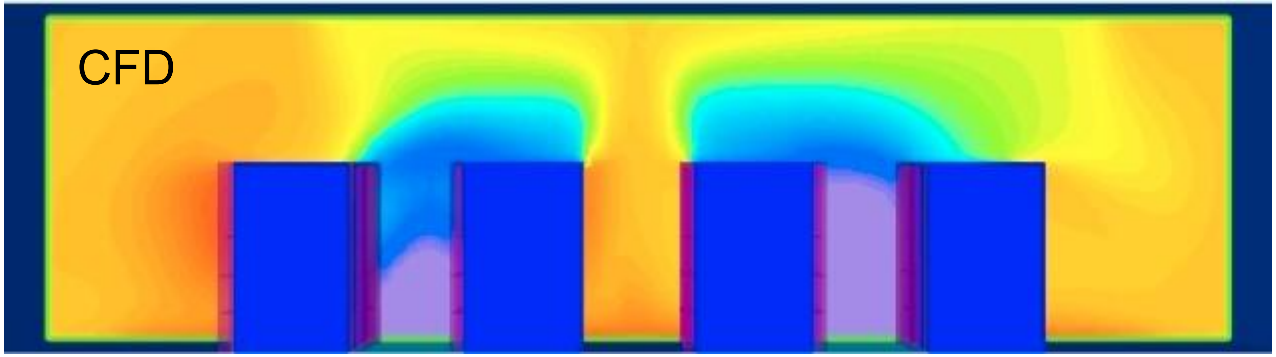
Better airflow management permits warmer supply temperatures.



Visualizing Temperature and Airflow

- Computational Fluid Dynamics (CFD) modeling
- Temperature sensor networks
- Infrared thermography





Air cooling issues

- Limitations on the data densities served
  - Air delivery limitations
  - Real estate
- Working conditions
  - Hot aisles are approaching OSHA limits
- Costly infrastructure
- High energy costs
- Management over time
- Reliability
  - Loss of power recovery
  - Particulates

Space zoning

- Some IT equipment (e.g. storage) requires tighter control
- Don’t penalize the whole center for a few pieces of equipment
- Different zones should be provided

Airflow Requirements

- Typically, much more air is circulated through computer room air conditioners than is specified by manufacturers due to mixing and short circuiting of air
- Computer manufacturers now provide ASHRAE data sheets which specify airflow and environmental requirements
- Evaluate airflow from computer room air conditioners compared to server needs

Best air delivery practices

- Arrange racks in hot aisle/cold aisle configuration
- Try to match or exceed server airflow by aisle
  - Get thermal report data from IT if possible
  - Plan for worst case
- Get variable speed or two speed fans on servers if possible
- Provide variable airflow fans for AC unit supply
- Consider using air handlers rather than CRAHs for improved performance
- Use overhead supply where possible
- Provide aisle capping
- Plug floor leaks and provide blank off plates in racks
- Draw return from as high as possible
- Use CFD to inform design and operation

State of the present: with air